



TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



Technology Focus



Electronics/Computers



Software



Materials



Mechanics/Machinery



Manufacturing



Bio-Medical



Physical Sciences



Information Sciences



Books and Reports

INTRODUCTION

Tech Briefs are short announcements of innovations originating from research and development activities of the National Aeronautics and Space Administration. They emphasize information considered likely to be transferable across industrial, regional, or disciplinary lines and are issued to encourage commercial application.

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Additional information announced herein may be obtained from the NASA Technical Reports Server: <http://ntrs.nasa.gov>.

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Innovative Partnerships Offices are located at NASA field centers to provide technology-transfer access to industrial users. Inquiries can be made by contacting NASA field centers listed below.

NASA Field Centers and Program Offices

Ames Research Center

David Morse
(650) 604-4724
david.r.morse@nasa.gov

Dryden Flight Research Center

Ron Young
(661) 276-3741
ronald.m.young@nasa.gov

Glenn Research Center

Kimberly A. Dalglish-Miller
(216) 433-8047
kimberly.a.dalglish@nasa.gov

Goddard Space Flight Center

Nona Cheeks
(301) 286-5810
nona.k.cheeks@nasa.gov

Jet Propulsion Laboratory

Dan Broderick
(818) 354-1314
daniel.f.broderick@jpl.nasa.gov

Johnson Space Center

John E. James
(281) 483-3809
john.e.james@nasa.gov

Kennedy Space Center

David R. Makufka
(321) 867-6227
david.r.makufka@nasa.gov

Langley Research Center

Michelle Ferebee
(757) 864-5617
michelle.t.ferebee@nasa.gov

Marshall Space Flight Center

Terry L. Taylor
(256) 544-5916
terry.taylor@nasa.gov

Stennis Space Center

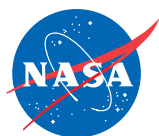
Ramona Travis
(228) 688-3832
ramona.e.travis@ssc.nasa.gov

NASA Headquarters

Daniel Lockney,
Technology Transfer Program Executive
(202) 358-2037
daniel.p.lockney@nasa.gov

Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) Programs

Rich Leshner, Program Executive
(202) 358-4920
rleshner@nasa.gov



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JWST Integrated Simulation and Test (JIST) Core

Modeling techniques and hardware models have potential commercial applications for projects that deploy similar solutions.

Goddard Space Flight Center, Greenbelt, Maryland

The James Webb Space Telescope (JWST) Integrated Simulation and Test (JIST) environment is a software-only system simulator that provides an environment to exercise JWST flight software subsystems and interfaces. JIST is capable of executing the unmodified flight software binaries in an operational environment that can be configured on a single personal computer. JIST utilizes the JWST ground system, ground system command and telemetry databases, simulated flight computers, instrument simulators, and environment simulators. Some of the capabilities provided by JIST include the ability to load and run any version of the flight software, inject errors (faults) from ground system test procedures, save simulation state (processor and simulators), and simulate external hardware devices. Many components are potentially reusable on future missions. In addition, the modeling techniques and

models have potential commercial applications for projects that deploy similar hardware solutions.

The IV&V Program does not have a means to exercise the JWST flight software subsystems in a repeatable and consistent fashion, and the IV&V Program does not have sufficient budget to set up a hardware-in-the-loop test environment. JIST provides a mechanism to set up a test environment for the IV&V Program to dynamically validate flight software behaviors and examine unexpected flight software behaviors (independent tests). JIST also has the potential to provide a means to validate new test procedures prior to executing on hardware-in-the-loop environments, decrease procedure development time, and provide a ground operations training platform.

JIST provides a cost-effective means for the IV&V Program to perform dynamic analysis on software systems; provides a test framework for mission opera-

tions teams; provides a cutting-edge test environment with accompanying tools; and makes testing embedded flight software test environments more accessible and convenient for users and testers.

JIST can be configured to execute on a single personal computer, and can test hardware faults in nominal and off-nominal conditions. It can save and reload test scenarios at any point during a test, integrate easily with commercial debuggers, utilize unmodified flight binaries, and not require hardware acquisition or maintenance.

This work was done by Brandon Bailey, Justin Morris and Mark Pitts of Goddard Space Flight Center; Daniel Nawrocki of Athena Sciences; Steven Seeger of MPL; Justin McCarty and Scott Zemerick of Galaxy Global Corporation; Jeffery Joltes and Tim Riley of Allegheny Science & Technology Corporation; and Charles Rogers of Embedded Flight Systems, Inc. Further information is contained in a TSP (see page 1). GSC-16739-1

Software for Non-Contact Measurement of an Individual's Heart Rate Using a Common Camera

John H. Glenn Research Center, Cleveland, Ohio

A software application detects the heart rate of an individual by using a real-time video stream from a common camera connected to their computer. This involves no contact between the user and the camera, or calibration between individual users. NASA's OpenMDAO framework was used to implement and coordinate the necessary data acquisition and signal processing functions.

The software finds the location of the user's face within an incoming stream of images from a connected camera, and then isolates the forehead region. Data is collected from this location for a segment of time to estimate the user's heart rate by measuring average optical inten-

sity in the forehead location, in the subimage's green channel alone.

A bandpass filter designed to isolate and magnify spectral components between 0.8 Hz and 3 Hz is computed on the gathered optical intensity data. With good lighting and minimal noise due to motion, a stable heartbeat is isolated in about 15 seconds. Accuracy has been tested against commercial heart rate monitors used for sports medicine.

Once the user's heart rate has been estimated, real-time phase variation associated with this frequency is also computed. This allows for the heartbeat to be exaggerated in the post-process frame rendering, causing the high-

lighted forehead location to pulse in sync with the user's own heartbeat.

This work was done by Tristan Hearn of Glenn Research Center. The application was developed at NASA Glenn Research Center in support of OpenMDAO, under the Aeronautical Sciences Project in NASA's Fundamental Aeronautics Program, as well as the Crew State Monitoring Element of the Vehicle Systems Safety Technologies Project, in NASA's Aviation Safety Program. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19090-1

Rapid Infrared Pixel Grating Response Testbed

NASA's Jet Propulsion Laboratory, Pasadena, California

A test array has been developed to measure the response of pixel-integrated infrared gratings over a wavelength range from 3 to 13 μm for multiple grating geometries. This array allows for testing and for determining the performance of an infrared focal plane array camera before resources have been committed to the design and fabrication of the final array.

The 320 $\times$ 256 array of 25- μm test pixels comprises five types of grating geometries with theoretical peak response varying in 0.25- μm steps from 3 to 13 μm . The array

has been designed to be hybridized to a FLIR-Indigo 9705 read out integrated circuit (ROIC). On the same lithographic mask as this array, large-area (200 μm) pixels have been designed with the same grating parameter sweep. Together the small and large area pixel comprise the rapid infrared pixel grating response testbed. This testbed pattern is typically fabricated on one of JPL's long wavelength infrared (LWIR) quantum well infrared photodetector (QWIP) wafers. The 320 $\times$ 256 detector array is then bonded to the FLIR/Indigo 320 $\times$ 256 ROIC, and used as the

electronic backbone of the testbed. The array is then thinned to replicate the characteristics of a standard deliverable camera array. Response of the test pixels is then measured and compared to the expected response. Shifts due to cavity and lithographic fidelity effects can be compensated for, and the final imaging array design can be made with confidence.

This work was done by Cory J. Hill, Jason M. Mumolo, and Daniel W. Wilson of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47823

Temperature Measurement and Stabilization in a Birefringent Whispering Gallery Resonator

Applications include optical clocks, spectroscopy, and optical transponders.

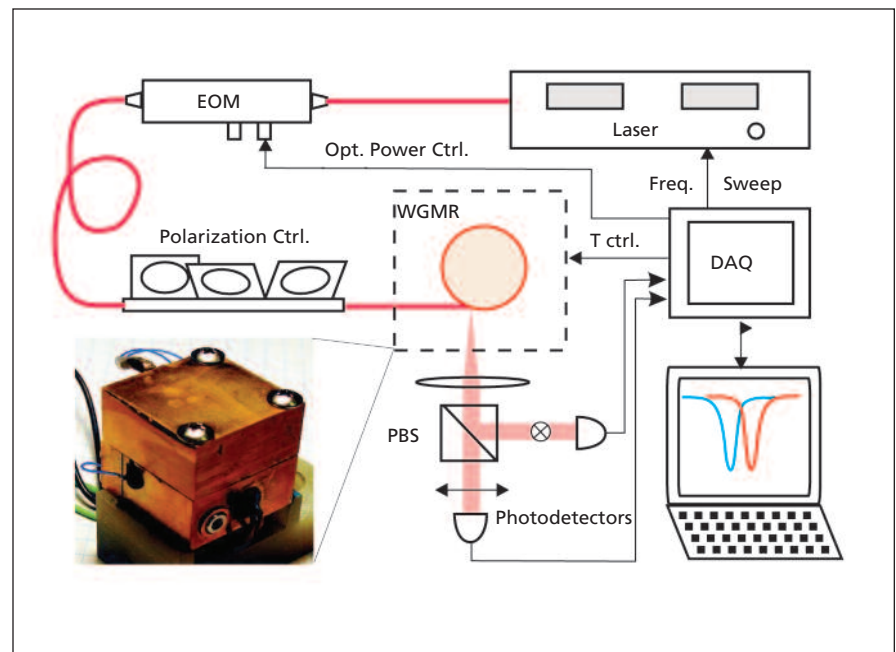
NASA's Jet Propulsion Laboratory, Pasadena, California

Whispering gallery mode (WGM) resonators have been suggested for use as reference cavities for laser stabilization. Because of their unique properties (small size, high stability, narrow line width), such application appears to hold great promise. It is expected to allow for the exceptionally high optical frequency stability.

The main practical difficulty associated with using WGM resonators for laser stabilization arises from the fundamental fact that the light propagates inside an optical material. This appears to be a disadvantage compared with low-expansion Fabry-Perot resonators that are essentially vacuum-filled. In WGM resonators, the material's optical properties set the limit not only for the resonator's Q-factor, but also for its stability.

The most important factors contributing to variation of the WGM resonance frequency are the thermal refractivity and thermal expansion. These variations can be suppressed if the resonator temperature is stabilized to the micro-Kelvin level. To achieve this, the temperature dependence of the resonator's own anisotropy is used.

Temperature dependence of the resonator anisotropy leads to a temperature-dependent frequency difference between the TE and TM mode families. This frequency difference can be measured with a high precision, and the tem-



The experimental setup of the **WGM Resonator**. Temperature of the brass cube in the photo is set to 76 °C and is stabilized to a few hundred nanodegrees using the dual-mode stabilization technique. (Note: EOM is electro-optic modulator, WGM is whispering gallery mode resonator, T ctrl. is temperature control, DAQ is data acquisition, and PBS is polarizing beam splitter.)

perature variations are extracted. These variations are then suppressed by two digital control loops.

The first practical implementation of the dual-mode stabilization approach has been achieved, and active temperature stabilization of a WGM resonator at above

room temperature has been demonstrated. Temperature stabilization at the level of 200 nK was achieved when integrated for one second, and below 10 nK when integrated for 10,000 seconds. This considerably surpasses state-of-the-art temperature sensors; especially tempera-

ture control techniques. This result is significant not only in the context of laser stabilization, but also as a demonstration of a novel temperature sensor with a broad spectrum of potential applications.

A WGM-based temperature sensor with nano-Kelvin sensitivity operating at room temperature was demonstrated. It was used to stabilize a WGM resonator at

the level of a few nano-Kelvin, which will allow use as an ultra-stable laser lock reference. The demonstrated technique can be used in a variety of other applications requiring high temperature stability, as well as ultra-sensitive measurements of temperature variations. These include thermal stabilization of a quartz oscillator, mid- or far-IR sensitive

bolometers, precise calorimetric measurements in chemistry, and study of optical and mechanical aging effects in various crystalline resonators.

This work was done by Dmitry V. Strekalov, Nan Yu, Robert J. Thompson, and Ivan S. Grudinin of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48222

JWST IV&V Simulation and Test (JIST) Solid State Recorder (SSR) Simulator

Dynamic analysis capabilities are provided with no hardware in the loop.

Goddard Space Flight Center, Greenbelt, Maryland

As described in "JWST Integrated Simulation and Test (JIST) Core" (GSC-16739-1) on page 25, the JIST system is a software-based simulator that uses the James Webb Space Telescope (JWST) operational ground system, ground system command/telemetry databases, simulated flight computers, and unmodified flight software binaries to provide dynamic analysis capabilities. There is no hardware in the loop; the flight software communicates over a simulated MIL-STD-1553 and Spacewire port. The JIST SSR Simulator is a reusable component of the JIST system, and is responsible for simulating basic SSR functionality.

In order to develop a software-only test environment for the JWST mission,

a solution was needed to simulate the behaviors of the JWST SSR. The as-is solution requires the utilization of an Excalibur 1002 Single Board Computer running custom software to simulate SSR functions and interfaces to the JWST Command and Telemetry Processor (CTP).

The JIST SSR Simulator is a component of the JIST system and is responsible for simulating basic SSR functionality. The primary purpose of the SSR Simulator is to assist in performing independent verification and validation (IV&V) of the flight software. The SSR simulator is a software-only simulator that provides the necessary interface to the JWST flight software and typically

simulates SSR management functions. Specific functions include playback, record, and telemetry transmission. The SSR simulator is also equipped with many different configurations that can be initialized using command line arguments.

The JIST SSR simulator is software-only and eliminates the need to acquire and maintain various hardware equivalent configurations. The simulator provides additional functionality and configurations to support specific independent testing objectives.

This work was done by Scott Zemerick of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16741-1



Development of a Precision Thermal Doubler for Deep Space

A copper thermal doubler is used to spread the thermal loads.

NASA's Jet Propulsion Laboratory, Pasadena, California

Thermal requirements and a need for a very flat mechanical interface led to the development of a copper doubler for the titanium vault on the Juno Spacecraft. The vault is designed to contain the science instruments on the spacecraft, protecting them from damage due to the extreme radiation environment of Jupiter. The titanium used in the vault creates unwanted thermal effects due to the poor thermal conductivity of titanium. To remove heat from the telecommunication equipment mounted to the interior of the vault, a copper thermal doubler was used to spread the thermal loads over the entire area of the radiator (located on the outside of the vault), which decreased the effective thermal resistance through the vault wall. A method of bonding a copper doubler to the titanium preserves the mounting interface flatness to less than 0.005 in. (0.13 mm) while providing a superior thermal path to the radiators, which are fitted with thermal control louvers. The precisely controlled titanium surface, and that of the milled copper doubler

with integral spacing features, provides the mechanical interface flatness, structural integrity, and thermal performance required by the telecommunications subsystem.

Utilizing precision milling techniques, a copper doubler was milled down to 0.065 in. (1.7 mm) to within ± 0.001 in. (0.03 mm). Then, the panel was undercut by 0.005 in. (0.13 mm) in all areas except where fasteners were placed. Around each fastener a boss was provided for good thermal conduction along with the maintenance of precision spacing of the component mounting surface. Bosses were also added in areas where no fasteners were needed to preserve the spacing between the copper and titanium. Precision milling of the part was chosen after blanchard grinding failed due to warping and galling of the copper. The copper thickness was such that a special vacuum fixture with liquid cooling was required. Weep holes were added to the bosses to allow for the excess bonding material to exit and not be trapped under the panel (which may

lead to flatness issues). Finally, the entire panel was bonded to the titanium using a precision 5-mil bond line established by the stand-off structures milled into the doubler.

This technique will result in a precision surface for the attachment of critical hardware that requires such a flat mounting surface, and provides the advantage of a mechanical thermal path at the bolted interfaces (a dry interface) while also proving a thermal interstitial material to fill all other voids (a wet interface) between the thermal doubler and the titanium panel. When properly prepared (including a primer), the RTV affords a bonded joint strength of approximately 500 psi (3.5 MPa) to provide structural integrity for the mounting of other parts.

This work was done by Kelley E. A. Alwood, Phillip A. Yates, Jerry J. Gutierrez, Gerald S. Gaughen, Bradley W. Kinter, Christopher C. Porter, and Terry Bennett of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47296

Improving Friction Stir Welds Using Laser Peening

This technique can be used in any application of friction stir welding, including automotive, railroad, and maritime industries.

Lyndon B. Johnson Space Center, Houston, Texas

Friction stir welding (FSW) has emerged as a promising solid-state process with encouraging results, particularly when used on high-strength aerospace aluminum alloys that are generally difficult to weld. Laser peening has been applied to friction stir welds in order to improve the mechanical and fatigue properties of welded joints. Laser peening introduces a compressive residual stress at the surface that can extend several millimeters or deeper into the material. These residual stresses resulting from laser peening can be significantly higher and deeper than for conventional shot peening, resulting in

superior mechanical and fatigue properties in FSW.

An increasing number of applications are using FSW to join materials that were not considered weldable using conventional fusion welding methods. However, the rigid clamping configuration required to clamp the parts during the FSW process, along with the heating cycle the material experiences during welding, can result in high residual stresses in the weld. These residual stresses, along with the reduction in properties from the welding process, are likely to affect the mechanical and fatigue properties and

therefore influence the in-service performance of structural components. The weld strength in some cases can be improved by post-weld heat treatment. However, this is not always an option in welded structural components. Consequently, laser peening was investigated as a means for improving the mechanical and fatigue properties in FSW.

For the laser peening process, different peening layers were used in an effort to identify the optimum number of peening layers capable of producing superior properties. The laser peening process was applied over the desired treatment area in a raster fashion.

The laser-peened samples displayed an approximate increase of 60 percent to the yield strength of the material. Conventional shot peening exhibited only a slight improvement to the tensile properties when compared to the unpeened FSW specimens. A subsequent investigation also revealed that laser peening resulted in a reduction in the grain size on the surface of the processed part, which may also explain some of the increase in tensile properties. However, the increase in mechanical properties from the laser peening was mainly attributed to the strain hardening, which can be explained by the generation of dislocations under the effect of the plastic deformation from the high energy laser peening. The resulting increase in dislocations tends to increase the flow resistance of the material to plastic deformation.

After the laser peening was applied, tensile residual stresses introduced during the welding process were found to become compressive. In general, the crack growth behavior in friction stir welded coupons is a function of microstructure, residual stresses, and specimen geometry. The results in this study indicate a significant reduction in fatigue crack growth rates using laser peening compared to the native welded specimens. This reduced fatigue crack growth rate was comparable to the base unwelded material. In contrast, shot peened specimens did not result in a significant reduction to fatigue crack growth.

Significant hardness improvement was achieved by processing the FSW 2195 aluminum alloy samples with laser peening. The laser-peened samples

processed using six layers exhibited a hardness increase of around 28 percent on the top surface, and a 21-percent increase on the bottom side of the weld nugget region. The hardness levels due to laser peening increased proportionally with the number of peening layers.

Corrosion behavior of laser peened FSW samples was investigated by submerging several specimens (some laser peened and some unpeened) in a sodium chloride solution for 60 days. After comparing the samples, it was noticed that the corrosion pits size and number were large on the unpeened surfaces, whereas they were much smaller on the laser treated surface.

This work was done by Omar Hatamleh of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24551-1

Methodology of Evaluating Margins of Safety in Critical Brazed Joints

Goddard Space Flight Center, Greenbelt, Maryland

This methodology provides a guide consisting of design, testing, and structural analysis steps developed to assure positive strength margins of safety (MS) in critical brazed joints used for assembly of flight and non-flight structures.

This effort was promoted by concerns expressed by industry and NASA engineers and program management that the current practices of assuring positive MS in structural brazed joints vary widely among the centers, NASA contractors, and manufacturers, making the verification of structural adequacy difficult in

cases involving multiple centers, other government agencies, and their suppliers. A lack of uniform methodology of estimating MS of the brazed joints leads to increasing cost of verification structural integrity of the critical hardware fabricated by brazing.

The methodology is based on testing standard butt- and lap-brazed test specimens to establish shear and tensile allowables, developing failure criterion in the form of interaction equations consisting of the stress ratios, and verifying this failure criterion by testing realistic or geometry-

specific test specimens representing the actual structure on a sub-component level.

The novelty of this methodology is that it is the first time that interactive equations were applied to the brazed joints. The methodology was verified on AlBeMet 162/AWS BAlSi-4, CRES 304/AWS Bag-8, Ti-6Al-4V/AWS Bag-8, Ticuni and Ti-6Al-4V/Al 1100 base metal/filler metal combinations.

This work was done by Yury Flom of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16042-1



Interactive Inventory Monitoring

This system queries the location and status of an item in an inventory.

Ames Research Center, Moffett Field, California

The invention is a radio frequency identity detector (RFID)-based system that assists a user in location of an item, in response to an electronic query for the status of the item. The item(s) being sought may be a book on a library shelf, an item from a store inventory, a legal or financial document, a medical record, a weapon system or weapon component (presumably) located in an armory, or similar item.

Each item is tagged by an RFID, which does not require a battery, but is preferably powered using an electromagnetic coil that is embedded in, or associated with, the item. The shelving, or other container, provides an alternating electromagnetic field to power the embedded coils, and can identify the item location if the item is on, or adjacent to, the shelving/container, even if the item is not in its assigned location. Each coil includes a low-power, programmable chip containing relevant information on the item (ID number, class to which the item belongs, present status of the item, relevant item characteristics, recent activity affecting the item, etc.). Removal of the item from the shelf/container may first require entry of specified information, including but not limited to user name,

user contact information, user priority level (if applicable), date the item was removed, and user authentication information. An associated light emitting diode (LED) array containing different colored LED light sources is optionally included for visual indication of location(s) of the item.

A desired item is specified and/or categorized using a database system with a computer interface. The interface may be a portable interrogator wireless electronic unit that communicates with the database, and with the item(s) sought. When the portable interrogator unit queries an RFID tag, the computer interface downloads information on the item from the database, and/or from the shelving/container (e.g. availability and/or recent location and/or present status of the item). Optionally, based upon a color code scheme assigned to the particular handheld unit, the shelving/container LED array displays the corresponding distinguishable color scheme wherever the item(s) is/are located.

This system can also provide security for an inventory of weapon systems, weapon components, and biological/mechanical warfare substances or other sensitive items that require extreme

protection. In this instance, the inventory receptacle is powered continuously, and each protected item emits a unique, encrypted code associated with the item, when the item is on, in, or adjacent to the receptacle at its assigned location. When the protected item is not on or adjacent to the receptacle at its assigned location, or is located elsewhere on or adjacent to the receptacle, an alarm or notification signal is issued by the system, indicating when the item was last sensed at its assigned location. Use of an encrypted code of appropriate complexity can minimize or eliminate the possibility of "spoofing" to cover absence of the protected item. Entry of an encrypted password allowing access to the protected item could be used to avoid prompt issuance of an alarm signal.

This work was done by Stevan M. Spremo and Usen E. Udoh of Ames Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at 1-855-NASA-BIZ (1-855-6272-249) or sumedha.garud@nasa.gov. Refer to ARC-15684-1.

Sensor for Spatial Detection of Single-Event Effects in Semiconductor-Based Electronics

The positional ionizing radiation sensor detects energy levels that cause faults in electronic circuits.

Marshall Space Flight Center, Alabama

Ionizing radiation has a detrimental effect on digital electronics that need to operate in extraterrestrial environments. As space missions become longer and more complex, there is a need for flight computers that can withstand harsh radiation environments while delivering the increased computation and power efficiency required by future missions. Field-programmable gate arrays (FPGAs) are becoming an attractive

platform for flight computers due to their inherent flexibility through in-flight reprogrammability. FPGAs promise to deliver reconfigurable computing platforms that can dynamically alter hardware architectures to address the current application demand. While FPGAs are attractive from a performance perspective, they can be especially susceptible to single-event effects caused by ionizing radiation. In addition

to traditional circuit faults caused by radiation, FPGAs are prone to faults in their configuration memory. These faults can physically alter the hardware, leading to failures that cannot be recovered from using traditional fault mitigation techniques.

A sensor was designed to detect the spatial location of radiation strikes of energy levels that can cause faults in commercial FPGA substrates. A tile-based

computing architecture has been designed to take advantage of the sensor information to spatially avoid regions with potential faults, and then perform a repair procedure in the background.

The sensor is integrated with the many-tile computing system implemented on an FPGA to provide environmental information to the computer in order to improve its fault tolerance. The X-Y location of ionizing radiation strikes is passed to the computer, and is used to spatially avoid and repair potentially faulted regions of the computer fabric.

There have been numerous sensor designs for monitoring position and energy

of radiation with variations in resolution and system integration. The design selected utilizes double-sided strip detectors and silicon drift detectors for their simple design, speed, and ease of production without sacrificing position and energy resolution. The principle of the strip detector is based on a large area p-n diode, very similar to a solar cell. The difference stems from the electrodes in the radiation sensor, which are broken up into narrow strips running orthogonal to each other on both sides of the substrate, each of them being read-out with a separate electronic channel. The location of the ionizing radiation is given by the po-

sition of the intersection of the strips receiving the signals from the front.

This sensor is unique in that it detects energy levels that are only capable of causing faults in semiconductor-based electronics. The use of the sensor to provide environmental information to a digital circuit so that the digital circuit can preemptively mitigate a possible fault is a novel use-model for a radiation sensor.

This work was done by Brock LaMeres and Todd Kaiser of Montana State University for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32975-1

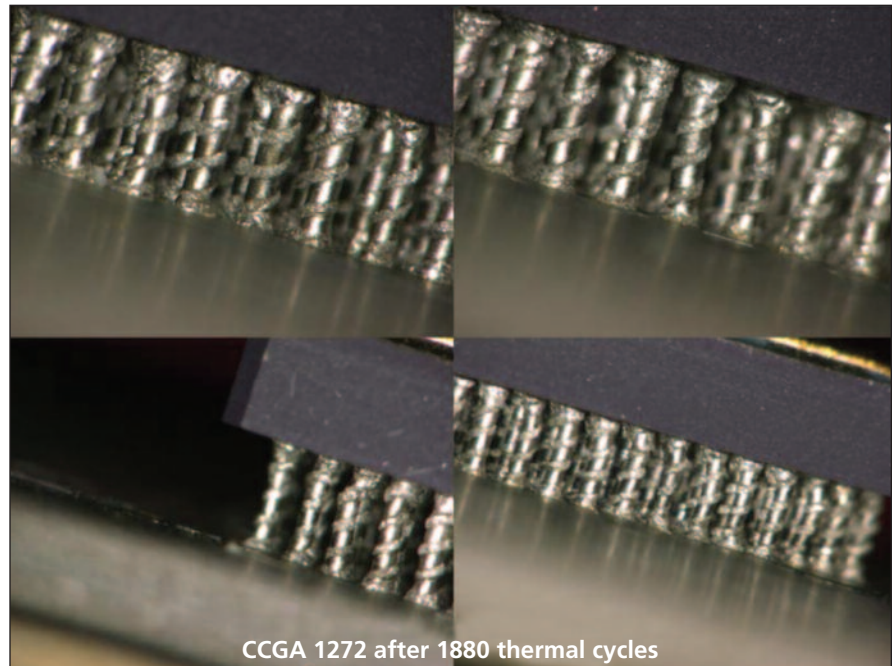
Reworked CCGA-624 Interconnect Package Reliability for Extreme Thermal Environments

The effect of the number of reworks is examined on the reliability of this technology for harsh, extreme thermal environments.

NASA's Jet Propulsion Laboratory, Pasadena, California

During the past two decades, large, high-density, high-input/output (I/O) electronic interconnect SMT (surface mount technology) packages such as ceramic column grid arrays (CCGAs) have increased usage in avionics hardware of NASA projects. The test boards built with CCGA packages are expensive and often require rework to replace reflowed, reprogrammed, failed, or re-designed CCGA packages. Theoretically, a good rework process should have a similar temperature-time profile as that used for the original manufacturing process of solder reflow. A multiple rework process may be implemented with CCGA packaging technology to understand the effect of the number of reworks on the reliability of this technology for harsh, extreme, thermal environments.

CCGA 624 packages have been increasing in use based on their advantages such as high interconnect density, very good thermal and electrical performance, and compatibility with standard surface-mount packaging assembly processes. Reworked CCGA packages are used in space applications such as logics and microprocessor functions, telecommunications, flight avionics, and payload electronic assemblies. As these packages tend to have less solder joint strain relief than leaded packages, the reliability of reworked CCGA-624 packages is very



Optical Photographs of the fatigued solder joints in a 1st Reworked CCGA 624 package after 1,026 thermal cycles of -185 to $+125$ °C.

important for short- and long-term space missions.

In general, reliability of the assembled electronic packages reduces as a function of number of reworks, and the extent of reliability loss is not known yet. A CCGA rework process has been implemented to design a daisy-chain test board consisting of 624 packages.

Reworked CCGA interconnect electronic packages of printed wiring polyimide boards have been assembled and inspected using non-destructive x-ray imaging and optical microscope techniques. The assembled boards after first rework were subjected to extreme temperature thermal atmospheric cycling to assess their reliability for future

deep-space mission environments. The resistance of daisy-chained interconnect sections was monitored continuously during thermal cycling to determine intermittent failures. This test

data shows a limitation of these reworked CCGA 624 packages for various projects. This research has reported the reliability study of CCGA 624 packages down to -185°C and up to $+125^{\circ}\text{C}$.

This work was done by Rajeshuni Ramesham of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-49083

Current-Controlled Output Driver for Directly Coupled Loads

This driver is relatively compact and less costly in reducing energy.

Lyndon B. Johnson Space Center, Houston, Texas

Driving loads such as electric motors, relay coils, and solenoids requires a relatively large initial pull-in or start-up current from a driver in order to initiate operation of the load. To maintain continuous operation, the hold or running operating current required for a load may be 20% or less of the initial pull-in or start-up current. The problem is that a standard driver circuit acting as a switch continues to provide the same current throughout operation, wasting energy, and must be large enough to provide the large current continuously.

A new driver provides a smaller, less costly method of reducing energy to drive the load. It uses a transformerless direct-coupled pulse width modulation (PWM) switching driver to control the current to the load. Circuit area is reduced by directly coupling the driver circuitry to the load, thus eliminating the transformer, diodes, and output capacitors. This invention does not provide the electrical isolation of the transformer-coupled topology or as wide an input voltage operational range. However, many applications do not require isolation or the wide operating input voltage range of the transformer-coupled

method. Therefore, they can benefit from the reduced energy consumption and circuit area of the direct-coupled topology described here.

This innovation uses electronic components that are assembled and interconnected on a printed wiring board to isolate the high and low side of a dual bus input. The driver circuit uses a PWM control topology with a series switching element. The PWM provides control of the output current by modulating the switching duty-cycle. The current may thus be controlled to any level desired using any number of potential algorithms. For example, the current feedback to the PWM control circuitry may be fed through a delay element that inhibits the current limiting for a period of time required for proper pull-in or start-up of the load. This provides two distinct levels of load current: a large initial pull-in or start-up current followed by the lower hold or running operating current. This could also be accomplished by simply timing the turn-on and switching between one or more control points as desired.

This driver can maintain a consistent level of isolation between independent

power inputs. No single failure within the avionics electronics will cause independent power buses to lose electrical isolation, and a simple diode O-ring cannot be used. These requirements apply to both supply and return lines.

The innovation also addresses a high-reliability problem of load control via electronic circuit breaker (ECB). ECB dynamic control can be implemented via simple FPGA (field programmable gate array) means.

This work was done by Nathan Moyer, Thomas Bingel, Deanne Tran-Vo, George Cebry, Paul Santrach, and Charles McCracken III of Honeywell for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act {42 U.S.C. 2457(f)} to Honeywell. Inquiries concerning licenses for its commercial development should be addressed to:

Honeywell

P.O. Box 52199

Phoenix, AZ 85072-2199

Refer to MSC-24766-1/7-1/76-1/82-1, volume and number of this NASA Tech Briefs issue, and the page number.



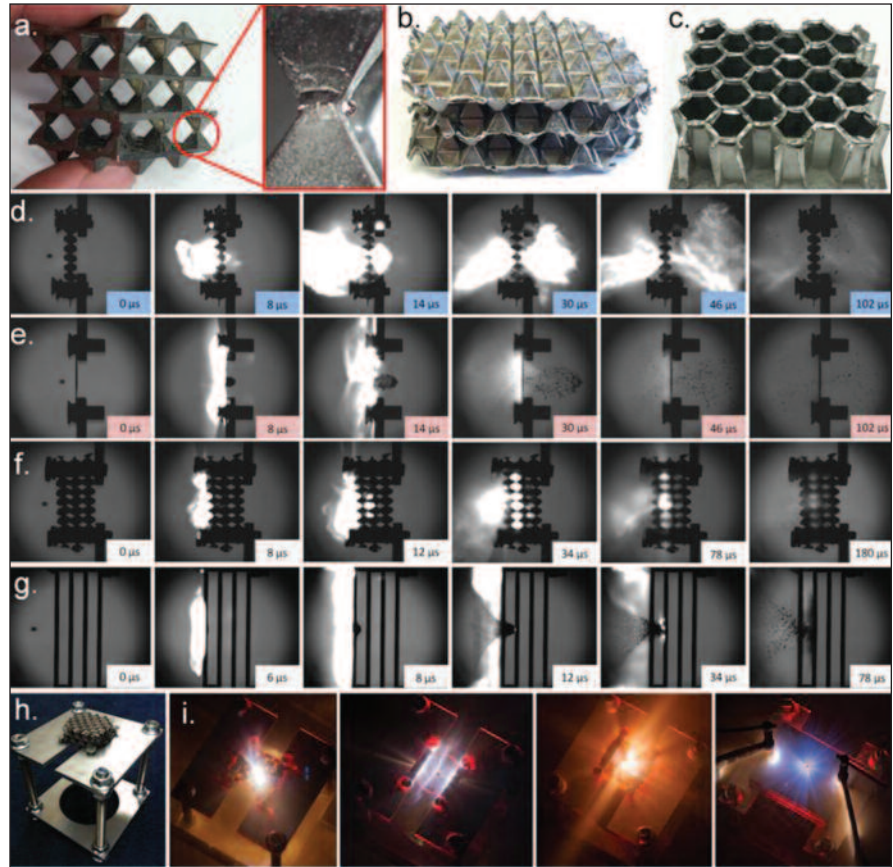
Bulk Metallic Glasses and Matrix Composites as Spacecraft Shielding

These materials offer combinations of high hardness, low melting temperature, low density, and formability like a plastic.

NASA's Jet Propulsion Laboratory, Pasadena, California

Spacecraft shielding is defined as the outer layer of a satellite or spacecraft that protects it against micrometeorite and orbital debris (MMOD), radiation damage, and re-entry temperatures. There are several problems with the design and implementation of shields, particularly in the area of MMOD shielding. Spacecraft and satellites need to have the lowest possible mass due to the enormous cost per pound of putting them into orbit or deep space. However, low Earth orbit (LEO) is currently littered (and increasingly so) with orbital debris, primarily remnants of rocket upper stages, satellites, and pieces of spacecraft that have broken away or have collided with other objects. The major threat is that this debris is traveling at 8 to 18 km/s, and any piece larger than a few centimeters has the kinetic energy to potentially become a "spacecraft killer." Large debris is tracked with radar, but the smaller debris (below a centimeter or so) is too small to track and must be mitigated by shields in the event of a collision. The International Space Station, for example, employs over 500 different shield designs into its outer skin, which are designed to protect a variety of vital components.

Designing new materials for MMOD shielding is a compromise among ballistic performance, areal density, volume, and geometry. Shields are often comprised of multiple materials stacked in layers or as foams and function by vaporizing, diffusing, and catching a projectile without compromising the inner wall of the spacecraft. Materials that have been used in shields include aluminum panels and foams, titanium, carbon fiber, Kevlar, and Nextel cloth, among others. Aluminum is widely used both as panels and as cellular structures due to its low areal density and easy fabrication; however, aluminum is a soft metal with a low ballistic limit compared with other metals (like titanium and steel, for example). Empirical ballistic limit equations have been developed for many potential



Sample Materials and Tests: (a) A four-layered bulk metallic glass matrix composite (BMGMC) cellular structure fabricated by capacitively joining individual layers (shown in the inset). (b) A three layer test panel of the BMGMC used for hypervelocity testing compared with (c) an aluminum honeycomb with the same thickness. (d-g) Hypervelocity impacts of 3 mm aluminum projectiles at ≈ 3 km/s into a variety of BMG and BMGMC panels. (d) Impact into a single layer of the BMGMC shown in (a). (e) Impact into a thin BMGMC panel with the same thickness as in (d). It is noted how the egg-box structure diffuses the debris versus the flat panel. (f) Impact into the panel in (b) showing no penetration. (g) Impact into a 4-layer BMG Whipple shield showing no penetration. (h) Example of the test panel used in (f). (i) Long exposures of the impacts in (d-g) where the light intensity indicates the energy absorbed during impact (the red line is the triggering light for the camera).

shield materials, which has lead to the observation that their hardness is one of the best indicators of shielding effectiveness. A new class of metal alloys, which seems to have an optimal combination of properties for MMOD shielding, are bulk metallic glasses (BMGs, also called amorphous metals) and their composite derivatives. BMGs are metal alloys that have been designed with chemical com-

position and high cooling rates such that they freeze in an amorphous (non-crystalline) state. This gives them unique mechanical properties, including ultra-high strength and hardness, low stiffness, density similar to titanium, and formability like plastics. BMG matrix composites, which are reinforced with soft, crystalline phases that grow as dendrites, are alternative materials that exhibit the same

beneficial mechanical properties as the monolithic BMGs, but with the added benefits of ultra-high fracture toughness and ductility, making them suitable for high-performance structural applications. Particularly, BMGs have high hardness (6 times harder than Al alloys), relatively low density (twice as dense as Al alloys), and low melting temperatures (the same as Al alloys), which makes them effective at vaporizing incoming debris while assuring that the part of the shield that is impacted also melts or vaporizes, preventing solid debris from hitting the spacecraft wall.

Over the last two years, JPL, in collaboration with Johnson Space Center and the University of Southern California, have been performing the first hypervelocity impact tests on BMGs and their composites, with promising results. Thin, corrugated panels of BMG composites, which have been formed into multi-layered cellular structures through capacitive joining, have shown to be extremely effective at mitigating impacts from Al projectiles (see the figure). In recent work, metallic glass sheets were substituted for Kevlar in shields designed for the International Space Sta-

tion and tested one-to-one against conventional shields at impacts up to 7 km/s. The new shields outperformed the heritage ones in the preliminary testing. Since BMGs and their composites can be formed into large sheets and panels with unmatched mechanical properties, they are potentially optimal materials for integration into future spacecraft and satellites.

This work was done by Douglas C. Hoffmann of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-48402

Touch Temperature Coating for Electrical Equipment on Spacecraft

Coating significantly increases the allowable touch temperature.

Lyndon B. Johnson Space Center, Houston, Texas

A coating has been developed that can be applied to spacecraft equipment to significantly increase the allowable touch temperature limit, while only marginally degrading the heat transfer to the environment.

The requirements for the coating are to:

1. Limit skin temperature levels below the pain threshold by:
 - a. Having low thermal mass.
 - b. Providing a resistance to heat flow when the object is handled.
2. Cause minimal degradation to nominal on-orbit heat transfer.

These requirements were met in a prototype by fabricating a layup consisting of, from top to bottom:

- A 0.004 in. (0.1 mm) thick aluminum outer layer,
- A 0.0023 in. (0.06 mm) thick high-temperature acrylic transfer adhesive,
- A 0.002 in. (0.05 mm) thick square

stainless steel fin with longitudinal waves that add crush strength,

- A second layer of transfer adhesive, and
- A second aluminum facesheet.

The two aluminum facesheets act as the outer heat transfer layer and the layer that bonds to the equipment. The facesheets are identical for convenience, but are sized by the requirements for the outer heat transfer layer.

In the crew cabin of a spacecraft, the heat transfer is a combination of convection to the free-stream air and radiation to the cabin walls. Because of the lack of buoyancy-driven natural convection and the low cabin airflow, the convective heat transfer coefficients are much lower than are normally found in terrestrial applications.

A mathematical heat transfer model showed that the coating dramatically improves the allowable object temperature for a given contact time — a 20 °F (11

°C) increase for long times and as much as a 100 °F (56 °C) increase for short times. The coating also improves the allowable time of contact for a given temperature. A bare 140 °F (60 °C) aluminum item can be held for 2.5 seconds without pain, but with the coating, it can be held for more than 2 minutes before pain is felt.

The coating could be used in terrestrial applications where similar requirements exist: surface coatings that allow ungloved handling of hot surfaces but minimally impede nominal heat transfer. For example, hot surfaces of powered equipment that must provide cooling, but can be inadvertently touched or handled during maintenance could be coated for safety.

This work was done by Eugene K. Ungar and Timothy K. Brady of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24726-1

Li-Ion Electrolytes Containing Flame-Retardant Additives

Battery improvements for portable electronics and electric vehicle applications can be realized.

NASA's Jet Propulsion Laboratory, Pasadena, California

In order to improve the safety and performance of lithium-ion cells, especially over a wide operating temperature range, a number of Li-ion electrolytes have been developed that contain flame-retardant additives in

conjunction with fluorinated co-solvents to provide a safe, wide-operating-temperature-range system. Previously, fluorinated esters were incorporated into multi-component electrolyte formulations and their performances

have been demonstrated over a wide temperature range (–60 to +60 °C). The fluorinated esters co-solvents were employed due to their favorable properties and improved safety characteristics, mainly associated with their low

flammability associated with their halogenated nature.

In the present work, the safety characteristics of these electrolytes have been further improved by the addition of flame-retardant additives, such as triphenyl phosphate (TPP), tributyl phosphate (TBP), triethyl phosphate (TEP), and bis(2,2,2-trifluoroethyl) methyl phosphonate (BTfEMP). A number of electrolytes based upon these approaches have delivered good performance over a wide temperature, good cycle-life characteristics, and improved safety characteristics; namely, reduced flammability. Thus, the following electrolyte formulations were investigated and demonstrated in experimental MCMB carbon-LiNi_{0.8}Co_{0.2}O₂ cells:

1. 1.0 M LiPF₆ in EC+EMC+TFEB+TPP (20:55:20:5 v/v %)
2. 1.0 M LiPF₆ in EC+EMC+TFEB+TBP (20:55:20:5 v/v %)
3. 1.0 M LiPF₆ in EC+EMC+TFEB+TEP (20:55:20:5 v/v %)
4. 1.0 M LiPF₆ in EC+EMC+TFEB+BTfEMP (20:55:20:5 v/v %)
5. 1.0 M LiPF₆ in EC+EMC+TPP (20:75:5 v/v %)
6. 1.0 M LiPF₆ in EC+EMC+TPP (20:75:5 v/v %) + 1.5% VC
7. 1.0 M LiPF₆ in EC+EMC (20:80 v/v%) + 1.5% VC

8. 1.0 M LiPF₆ in EC+EMC (20:80 v/v%) (baseline)

Of the electrolytes studied, 1.0 M LiPF₆ EC+EMC+TFEB+TPP (20:55:20:5 v/v%) (where TPP = triphenyl phosphate) was identified as being a promising non-flammable electrolyte, due to reasonable low-temperature performance and superior life characteristics. In addition, the electrolyte consisting of 1.0 M LiPF₆ EC+EMC+TPP (20:75:5 v/v%) + 1.5% VC was demonstrated to have even further improved life characteristics due to the incorporation of a solid electrolyte interphase (SEI) promoter (i.e., VC = vinylene carbonate), which appears to inhibit the decomposition of the TPP.

A number of experimental Li-ion cells, consisting of MCMB carbon anodes and LiNi_{0.8}Co_{0.2}O₂ cathodes, have been fabricated to study the described technology. These cells serve to verify and demonstrate the reversibility, low-temperature performance, and electrochemical characterization techniques. All cells displayed good reversibility at room temperature and minimal reactivity during the formation cycling. The high coulombic efficiency and comparable irreversible capacity losses are indirectly related to the overall stability of the solutions and the electrode filming characteristics. Reasonable reversibility

was observed with the cells containing all the electrolyte variations, when compared after the formation cycling. Some variation in capacity was due to different electrode weights, and not to electrolyte type, so most comparisons were expressed in terms of percentage of initial capacity under ambient temperatures. Triphenyl phosphate displayed the lowest irreversibility capacity losses and the highest coulombic efficiency, suggesting that it is not electrochemically decomposing and participating in the electrode filming process deleteriously.

This work was done by Marshall C. Smart, Kiah A. Smith, and Ratnakumar V. Bugga of Caltech and Surya G. Prakash of the University of Southern California for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

*Innovative Technology Assets Management
JPL*

*Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099*

E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-46262, volume and number of this NASA Tech Briefs issue, and the page number.



✦ Autonomous Robotic Manipulation (ARM)

This sensor-driven, model-based approach can be applied to small-batch manufacturing processes and explosive ordnance disposal.

NASA's Jet Propulsion Laboratory, Pasadena, California

Autonomous robotic manipulators have the potential to increase manufacturing efficiency, provide in-home care, and reduce the risk to humans in hazardous situations. The current challenge in autonomous robotic manipulation is to approach the capabilities of dedicated, one-off manipulators in known environments with versatile, inexpensive, and ubiquitous manipulator systems that can operate in a range of environments with only high-level human input.

A sensor-driven, model-based approach continually uses environmental interactions to update the system state, and then uses these state estimates for planning and control.

Instead of using the traditional sense-plan-act paradigm for planning and control execution of a robot, this innovation uses continuous estimation of the entire system state to update and then pre-plan actions, which are also deliberately executed, thereby increasing system state knowledge. This is done not only for a specific task, but is done across all tasks.

In general, the autonomy approach presented here conforms to standard system decompositions: Objects and the environment are first segmented, classified, and localized using vision. Based on the system state and models of the environment, optimal grasp sets, manipulation strategies, and collision-free motion paths can be computed. As environmental interaction occurs, more sensors such as tactile, force, and strain sensors can be fused with visual sensing to pro-



The **ARM Robot** is depicted picking up a screwdriver.

vide updates of system state. Real-time execution of task objectives, using feedback from sensors and state estimation, drives system actuators. For all tasks, including drilling, unlocking, opening, actuating, and grasping of various objects, a single strategy is used. Two diverse examples of picking up a screwdriver and unlocking a door are described in this general manipulation framework:

1. Non-Contact Perception, in which only visual sensors are used to seg-

ment, classify, and localize objects in the scene, and determine their pose relative to environmental constraints (such as a table or wall/door plane).

2. Approach, where using the initial system state estimates, optimal arm, neck, and finger trajectories are planned to bring the manipulator near the object in a manipulatable configuration. In the case of the screwdriver on the table, the grasp set will include a caging grasp, where widely spaced fingers and the table prevent object escape. For key insertion, the hand is brought near the door handle.
3. Initial Contact/Relocation, where the manipulator is in the same field of view as the relevant objects, and estimation of the arm position (arm tracking) allows the control to provide more precise relative hand-to-object motions. For all tasks, a general contact strategy, where parts of the manipulator are moved into contact with the environment, is used to provide further relative localization.
4. Grasping or Manipulation, where once sufficient relative object localization has been achieved, controlled execution of the primary specified task objective (drilling, grasping, compression, actuation, etc.) is conducted.

This work was done by Nicolas H. Hudson, Thomas M. Howard, Paul G. Backes, Abhinandan Jain, Max Bajracharya, Jeremy C. Ma, Joel W. Burdick, Paul Hebert, and Thomas F. Allen of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-48095



CARVE Log

This software reduces the workload of the mission manager by distributing selected aircraft data to the various investigators onboard the aircraft so they do not have to continuously request the data updates. This system will then send the investigator's comments and observations that were previously written in notebooks to a server that archives them in a file for later reference.

CARVE log is a system consisting of a server and an Apple iPad app. The iPad app displays aircraft attitude, location, and other selected data to the user, and allows the user to type in comments that are tagged with the user's initials and sent to the server over wireless Internet.

The server receives the comments from the app and stores them in a text file on the disk, appending to it the most recent aircraft location and attitude information. This appended information serves as a time stamp for the comments and observations. The data acquisition programs also send the names, start, and stop times of their data files to the server, tagged with their instrument identifier, removing the need to log manually this critical information.

This work was done by Steven J. Dinardo, Seth L. Chazanoff, and Charles E. Miller of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48397.

Platform Perspective Toolkit

This software specializes in discovering the location and intrinsic parameters of an imaging camera when such information was not recorded in the metadata of an image. It provides a simple command line interface for specifying the input and output for the two camera perspectives.

Using the `Get_Platform_Perspective.m` function, for a given image, it discovers the position and intrinsic parameters of the camera that took the image. Points in the scene must be correlated to points in real space, typically represented in latitude, longitude, and altitude.

Using the `Apply_Platform_Perspective.m` function, the software transforms an image captured by a known camera at a known perspective to simulate the image captured from an alternate perspective and/or camera.

A straightforward interface with the algorithm allows this to be integrated into a variety of other programs, or used as a standalone analysis tool. Obtaining the platform perspective is a key step in image chain modeling, which aids in the design of new sensor systems.

The toolkit also is useful for simulating alternate views of a scene. This is useful for Earth-observing satellites that are in constant motion and, therefore, are constantly changing their perspective.

This work was done by Steven J. Lewis, David M. Palacios, and Michael C. Burl of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48256.

Convex Hull-Based Plume and Anomaly Detection

A number of deep space missions have imaged plumes at Io, Enceladus, and other smaller bodies. These phenomena provide valuable information regarding these bodies. To date, this imagery has been captured fortuitously. The ability to utilize onboard processing to conduct campaigns capturing large numbers of images and to detect when a plume event is occurring would open up new mission paradigms. Extended temporal campaigns could provide comprehensive detail on these events' frequency and character.

This software enables detection of plumes and obtrusions from irregularly shaped bodies. It finds convex hull from edge detection. It is very computationally efficient, and works with irregularly shaped bodies.

Onboard plume detection will enable much more efficient monitoring of outbursts and other dynamic phenomena. These techniques can enable a new class of missions to conduct long-term continuous monitoring of moons, planets, and comets.

This work was done by David R. Thompson, Steve A. Chien, Daniel Q. Tran, and Re-

becca Castano of Caltech; and Ronald Greeley and Melissa Bunte of Arizona State University for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48432

Pre-Filtration of GOSAT Data Using Only Level 1 Data and an Intelligent Filter to Remove Low Clouds

Software has been developed that mitigates anomalously low CO₂ retrieval values, due to low-lying clouds, for improved CO₂ sensing accuracy. Using machine learning techniques, hand-labeled data was used to train intelligently a multivariate least-squares filter using only five input-level-one features that detect low-lying clouds over ice with more than 99% accuracy. These input features are simple arithmetic operations on the input spectrum such as max, min, std, and mean.

Performing a full CO₂ retrieval from the GOSAT (Greenhouse gases Observing SATellite) data soundings is time-intensive (at 20 minutes per sounding). As ACOS (Atmospheric CO₂ Observations from Space) is a preparatory task for the Orbiting Carbon Observatory-2 (OCO-2) coming mission in which data volumes will be much higher, using the GOSAT environment to test and develop intelligent filters that can predict failed or useless retrievals before significant computational power has been wasted is a high priority.

This work was done by Lukas Mandrake of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48057.

Affordability Comparison Tool — ACT

ACT is able to provide insight into acquisition, operational, and lifecycle affordability early in program formulation prior to a commitment of architecture, or anytime during the program to change systems or subsystems. ACT analyzes different systems or architecture configurations for affordability that allows for a comparison of total lifecycle cost, annual affordability, cost per

pound, cost per seat, cost per flight (average), and total payload mass throughput. Although ACT is not a deterministic model, it does use characteristics (parametric factors) of the architectures/systems being compared to produce important system outcomes (figures-of-merit). The outcome figures-of-merit provide the designer with information on the relative affordability of different configurations.

ACT is spreadsheet-based and contains a set of algorithms that processes system configuration and characteristics to a measure of system affordability. Parametric factors are derived from quantifiable data about each system configuration's attributes. An initial algorithm converts quantifiable system configuration and characteristics data into a parametric factor for architecture/system complexity. The next set of ACT algorithms processes the complexity into system affordability figures-of-merit. These algorithms are initialized using known space transportation data to "anchor" embedded values in the algorithms. While the Space Shuttle was initially used for the comparisons, a database of other anchors is envisioned.

The algorithms allow the comparison of standard processes embedded with mathematically consistent values. This will not necessarily produce an exact forecast (deterministic cost number), but instead provide consistent figures-of-merit suitable for surfacing more affordable and productive alternatives.

ACT is scalable in that it can compare architectural design concepts of large-scale systems (elements) down to subsystems. Although the configuration of these systems may be vastly different, ACT can make functional comparisons based on multiple system attributes.

This work was done by Carey McCleskey, Timothy Bollo, and Jerry Garcia of Kennedy Space Center. For more information, contact the Kennedy Space Center Technology Transfer Office at (321) 867-5033. KSC-13714

"Ascent — Commemorating Shuttle" for iPad

A feature-added, interactive version of the video release entitled "Ascent" was developed. The software version contains the full HD (high definition) movie along with extra scenes, still imagery, a movie trailer, and producer notes. The software has been packed as an iOS app, intended for use on the iPad.

The software app provides the ability to include all features of the original

DVD and include additional interactive features to enhance the user experience. The distribution mechanism of Apple's "App Store" provides a cost-free mechanism to disseminate educational and informational NASA material to the general public.

The objective of this work was to disseminate the video released on DVD with value-added features and without incurring distribution and media costs.

This work was done by Gerald Nolan, Eric Mindek, and Matt Melis of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18811-1.

Cassini Mission App

This iPhone/iPad application allows the general public to access information about the Cassini mission. It enables viewing of the latest images released by the mission, allows access to images that describe the present position of the spacecraft, and provides flyby countdowns for each targeted flyby.

The software was developed using the Apple iOS SDK, and utilizes components inherent to that SDK to deliver images and other content on the iOS platform. It retrieves content from the public Cassini Web site using HTTP, XML, and JSON.

The software is a direct link to the general public from Cassini-related images and other information, and is intended to help spark interest in space exploration.

This work was done by Alice S. Wessen and Kirk Munsell of Caltech and Harman G. Smith and Joseph A. Wieclawek III of Raytheon for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-47866.

Light-Weight Workflow Engine: A Server for Executing Generic Workflows

The Light-Weight Workflow Engine (LWWE) is a cross-platform server that provides support for automation and orchestration of task execution.

The workflow tool is able to automate

and orchestrate a number of independent and dependent workflow tasks that can have dependencies on time, execution counts, and the execution status of other tasks. These tasks perform internal or external process execution and report execution status of those processes, as well as being able to control tasks on a limited basis (restart, suspend at startup, abort, etc.). An example of such tasks would be running preparation and execution scripts for scientific models. Since execution state is tracked, workflows are able to resume in the event of system failure.

At NASA, users generally use run scripts to execute large sets of commands. This is all performed within a terminal. Monitoring the execution of the scripts usually meant watching output or checking batch job queues. The NASA Experiment Designer (NED) workflow software (of which LWWE is a component) is intended to assist in the configuration, operation, and monitoring of these scripts. Previously the NED software had been using the SMS software from the European Centre for Medium-Range Forecasts (ECWMF) as the workflow component. The LWWE software is the replacement for SMS.

LWWE is pluggable software that can be embedded in other software or run standalone. The APIs include socket and command line interfaces, as well as extension points for implementing more complex custom tasks. External processes such as scripts or operating system commands can be launched and monitored. Workflow state is persisted to allow the engine to restart workflows from a recently known state (with the caveat that external processes must handle their own restart correctly).

This work was done by Shawn Freeman of Northrop Grumman Information Systems for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16083-1

Model for System Engineering of the CheMin Instrument

A computer program implements a model of the performance of the CheMin (Chemistry and Mineralogy) instrument — a miniaturized instrument that simultaneously performs x-ray diffraction (XRD) and x-ray fluorescence (XRF) measurements on small material samples. The CheMin instrument is being developed for use in exploring Mars and possibly other extraterrestrial bodies.

The model consists mostly of submodels of the XRD and XRF performance. The model is intended to be used by the instrument-development team for system-engineering purposes, notably including (1) verification or establishment of the flow of requirements from scientific objectives to instrument-design and -performance parameters; (2) assessment of effects, on performance, of changes in design and/or nominal oper-

ating conditions; and (3) improvement of the ability of the team to interpret data from experiments on other instruments or on breadboard versions of instrument systems.

The model is meant to be used to perform rapid approximate analyses of behavior of the instrument as a whole. It is expected that detailed examinations of higher-order effects will be done separately. Results from those ex-

aminations should be incorporated into the model in simplified form as they become available.

This program was written by Curtis W. Chen of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-44702.



Timeline Central Concepts

The Timeline can be used in ground operations software for manned, robotic, or mixed missions.

NASA's Jet Propulsion Laboratory, Pasadena, California

The notion of Timeline has been used informally in spacecraft operations software for some time, but it has not heretofore been formalized and unified either syntactically or semantically. In this work, the Timeline has been formalized and unified so that the commonality can be exploited to reduce the cost of developing and using spacecraft operations software. The Timeline can then be used as the common data structure for storage and communications between spacecraft planning and operations software elements.

Most spacecraft planning and operations processes are naturally expressed in terms of software tools that read timelines from databases as input and generate results as new or modified timelines that are written to the databases. Timelines are rigorously versioned, and each version is immutable — thus, a versioned timeline name forever represents exactly the same contents. The name is therefore as good as the contents, and the need for keeping files of contents for communicating between programs, or for associating several timelines or even values on those timelines, or for keeping a record of past values, is eliminated. Timelines thus form the syntactic and semantic method of integration of software elements, leading to decreased adaptation cost.

Operations efficiency is increased because historically segregated elements are easily integrated so that there are fewer gaps in the operations process that must currently be closed, if they are closed at all, by expensive or inefficient means.

The Timeline is abstractly defined as a container of items indexed by time, or of items related by time. The abstract definition is intentionally rather open, and the edge between timeline and not-timeline is fuzzy. The abstract definition does not need to be formalized, because it is the type of timeline that is actually defined that has practical impact. Timelines are made practical by creating concrete types of timelines that can be precisely defined, stored in databases, manipulated in software, and so on.

Timeline instances are stored in timeline databases (TLDBs). All TLDB instances must have two properties beyond the obvious of providing for the storage and retrieval of timelines: they must be rigorously versioned, meaning that in principle every change to a timeline creates a new version of that timeline; and they must provide version immutability, meaning that once a version is created, it is never changed. The reason for this is so that a timeline name and version together precisely represent the contents of that timeline at some instant in time.

The Database Interface is a key architectural invariant, along with the Timeline. It is designed to allow the database technology to be selected to meet mission needs. For example, a small mission may choose to use a free database. A larger mission may choose to use a commercial database that provides robust hot backups, offsite mirroring, local caching, and the like. A mission may choose to put the data in a commercial cloud. It may even change DB technologies over the life of the mission, using something cheap and light in formulation, heavy in operations, and optimized for archival access in perpetuity. The interface stays the same no matter what technology is used by a project, so that the spacecraft operations software suite will operate the same regardless of the DB technology used.

Interfaces can be added and extended, so that when a new timeline major type is introduced, the interfaces can be systematically extended to support the new timeline type.

This work was done by William K. Reinholz of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

The software used in this innovation is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48353.

Parallel Particle Filter Toolkit

Particle filters in real-time applications will bring unprecedented accuracy and applicability to aircraft and spacecraft navigation.

John H. Glenn Research Center, Cleveland, Ohio

Research on using inexpensive and personal-level parallel computing architectures to speed up the implementations of the class of particle filters has been conducted. This study leverages NVIDIA Graphics Processing Units (GPUs) and multi-core CPUs (central processing units) that are quickly becoming commonly available for engi-

neering communities. Parallelization of the unscented Kalman filter and the bootstrap particle filter, with applications in a GPS/INS (global position system/inertial navigation system) integration problem and an orbital determination problem, has been the focus of this research. It has been shown in this research that an 8-times

speedup can be achieved for the unscented Kalman filter implementations with an 8-thread CPU, and up to 2 orders of magnitude speedup can be achieved using an M2090 GPU.

The results also show that real-time applications for both unscented Kalman filters and particle filters are feasible for the two benchmark prob-

lems considered. The parallelized particle filter for both benchmark problems completes a 1-s filter cycle in under 0.23 s. It also demonstrates that parallel modules can be made as a black box that can interact with third-party serial programs, but require minimum knowledge from the user on how to parallelize a problem or on how to write a parallel program.

This research contributes to upgrading the current fleet of NASA navigation software that heavily relies on the Kalman filter and the Extended Kalman Filter (EKF), which can fail in nonlinear applications with non-Gaussian noise models. Advanced filters, like the sigma point and particle filters, are more accu-

rate than the EKF for nonlinear and non-Gaussian noise models.

One drawback of the particle-based filters is the excessive computational burden if implemented on a serial computer. However, because a majority of the computation can be carried out simultaneously, the particle filters inherently are well suited for parallel computing. The objective of this effort is to leverage GPUs and multi-core CPUs to exploit such parallelism. With the performance of these devices improving at a rapid pace, it is anticipated that they will quickly find their way to onboard avionics. This research paves the way for implementing particle filters in real-time applications. This will

bring unprecedented accuracy and applicability of particle filters to aircraft and spacecraft navigation analyses for NASA, and for a wide range of non-NASA applications.

This work was done by Haijun Shen and Christopher D. Karlgaard of Analytical Mechanics Associates, Inc., and Ryan P. Russell, Vivek Vittaldev, and Etienne Pellegrini of The University of Texas, Austin for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19021-1.

➤ Particle Filter Simulation and Analysis Enabling Non-Traditional Navigation

Goddard Space Flight Center, Greenbelt, Maryland

Particle filters (PFs) offer the possibility of addressing many unsolved problems in orbit determination and prediction. This work builds on an existing GSRP (Graduate Student Researchers Project) effort to incorporate a particle filter into GSFC's (Goddard Space Flight Center's) Orbit Determination Toolbox (ODTBX). Extensions were investigated that partition the particles into subsets based on *a priori* errors, measurement noise, process noise, and maneuver execution errors. Parallel computing was used to efficiently implement a suffi-

ciently large number of particles to begin solving significantly non-Gaussian estimation problems.

The work builds on ODBTX's inherent capability to distribute computations over multiple computational cores, which will prove complementary to the structure of the PF, since computations involving each particle can be assigned to their own core.

The PF estimator added to ODBTX, when running on a multicore server, will enable GSFC navigation analysts to tackle previously daunting navigation

challenges, such as simultaneously determining the orbit around, and characterizing the properties of primitive solar system bodies. It will provide a benchmark for the current suite of orbit estimators, uncovering any shortcomings that arise from Gaussian assumptions in the current estimators.

This work was done by John A. Gaebler, Alinda Mashiku, and Russell Carpenter of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16608-1

➤ Quasi-Terminator Orbits for Mapping Small Primitive Bodies

These orbits enable surface mapping without maneuvers when solar pressure is strong.

NASA's Jet Propulsion Laboratory, Pasadena, California

A common objective for primitive body missions (i.e., those to asteroids, comets, and small planetary moons) is to map the target body surface as completely as possible. Ideally, this map is constructed from a large collection of images containing multiple views of every point on the surface in a variety of lighting conditions and from a variety of viewpoints. For most missions to near-Earth objects (NEOs), the inherent instability of the orbital environment due to solar radiation pressure (SRP) necessitates a mapping

trajectory strategy that requires deterministic maneuvers every few days for several weeks to achieve the desired imaging geometries. The recently discovered quasi-terminator orbits (QTOs) offer an alternative approach that can achieve the imaging geometries needed for mapping without any deterministic maneuvers. By eliminating the need for frequent maneuvering, QTOs can significantly reduce the complexity and intensity of global mapping operations for robotic or manned missions to NEOs.

QTOs are quasi-periodic orbits that are derived from the well-known, stable terminator orbit solutions to the SRP-perturbed orbit dynamics at primitive bodies. Terminator orbits are not generally suitable for mapping because the phase angle (i.e., the Sun-body-spacecraft angle) stays nearly constant around 90°, which constrains the surface viewing and illumination geometries. However, the quasi-periodic oscillatory motion around a stable terminator orbit can be computed explicitly and ampli-

fied using tools from dynamical systems theory. The QTOs that result can achieve phase angles as low as several 10s and as high as $\approx 150^\circ$ while retaining the stability and robustness properties of the terminator orbits. The resulting variety of relative geometries allows for the surface imaging across a range of solar incidence angles, emission angles, and emission azimuths.

The QTOs have been derived using normalized coordinates such that the solutions only depend on the relative strength of solar pressure versus gravity ("beta"). Applicability to a particular mission can quickly be assessed from published plots of orbit period, minimum radius, and maximum radius for any mission beta. Generally speaking, QTOs are most often applicable for beta

values corresponding to robotic missions to NEOs or manned missions to very small NEOs.

This work was done by Stephen B. Broschart, Gregory Lantoine, and Daniel J. Grebow of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48915

The Subgrid-Scale Scalar Variance Under Supercritical Pressure Conditions

NASA's Jet Propulsion Laboratory, Pasadena, California

A quantity called "the conserved scalar" is very important in the modeling of turbulent reactive flows in large eddy simulations because, if it can be defined, it numerically simplifies the solution of the conservation equations by confining the reaction term to a single-species equation. This conserved scalar is assumed to have the statistics of a beta probability distribution function, and is thus determined by its first two moments of the distribution. The mean is computed as part of the general solution of the governing equations. However, the second moment, which is the variance at the scale smaller than that of the grid used for computation, is not known. For subcritical-pressure flows, an equation is usually derived for the

scalar variance, and since all terms of the equation are not calculable from the solution of the governing equations, some of these terms are modeled and the scalar variance equation is then solved. The problem is that under supercritical conditions the scalar variance equation is considerably more complex, a fact that begs the question whether the same methodology can be used for the important applications where the pressure is very high with respect to the critical point.

The scalar variance equation was derived under supercritical conditions, its terms were analyzed, and it was shown that new terms never modeled before are now important. Two methods were devised to model accurately the scalar

variance and filtered, non-linear functions of it, such as the dissipation.

A database of direct numerical simulation was used to: (1) examine the magnitude of the new terms in the subgrid scalar variance equation, (2) inquire whether the scalar has a probability distribution function of presumed shape, (3) develop directly two models for the subgrid scalar variance, and (4) show how these models portray non-linear functions of the conserved scalar when the scalar is assumed to have a presumed probability distribution shape.

This work was done by Josette Bellan and Enrica Masi of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-48078.

Sliding Gait for ATHLETE Mobility

A new concept was developed for a walking-driving hybrid in which wheels are repositioned by sliding them along the ground.

NASA's Jet Propulsion Laboratory, Pasadena, California

ATHLETE (All-Terrain Hex-Limbed Extra-Terrestrial Explorer) is a multipurpose mobility platform for planetary surfaces. It is a cross between a wheeled rover and a walking robot, and travels using powered wheels mounted on the end of each of six robotic limbs. Each limb is a fully articulated robotic manipulator with six or seven degrees of freedom.

ATHLETE's wheel-on-limb mobility design provides great flexibility for mobility over different types of surface features. Using the wheels to drive is highly efficient over benign terrain. However, to support the limbed design, ATHLETE uses wheels with lower

torque and smaller diameter relative to the robot's size and weight, as compared to wheeled-only rovers like the Spirit and the Opportunity. This lowers the overall surface pressure on the wheels, making ATHLETE vulnerable to slipping or embedding in soft terrain, and wheel stalling on steep terrain when traction is good.

ATHLETE's limbed design makes it possible for the robot to extract itself from such situations by locking the wheels and employing a walking gait. While these two mobility modes, driving and walking, provide ATHLETE with mobility solutions over any type of terrain,

ATHLETE's complexity and flexibility make possible the development of hybrid mobility modes that combine aspects of both driving and walking. A mobility mode that enables faster forward progress than walking over terrain unsuitable for driving is particularly desirable.

A new concept was developed for a walking-driving hybrid in which wheels are repositioned by sliding them along the ground, rolling the wheels in coordination with the motion of the limb. This mobility mode is referred to as the Sliding Gait, or SGait. For soft, loose, or steep terrain, in which wheeled roving fails, SGait enables mobility by allowing

some wheels to be repositioned while other wheels act as anchors. Because all six wheels maintain contact with the ground at all times, SGait motions easily maintain a conservative polygon of support, allowing efficient multi-limb gaits like the alternating tripod gait to be used for a significant time savings over free walking. Using force feedback while rolling wheels extends the usefulness of SGait to terrain that is rutted, bumpy, or strewn with small obstacles, as force control can be employed to maintain favorable wheel loading as the limb complies to terrain features.

The SGait algorithm uses the kinematic capability of ATHLETE's limbs to reposition wheels independently of the

robot's payload deck while keeping them in contact with the ground. The wheel is rolled along the ground in coordination with limb repositioning. This can be done for individual wheels or groups of wheels, allowing the approximation of any six-limbed walking gait. Between or during wheel repositioning motions, the payload deck is shifted to maintain a desired stable position above the wheels.

The SGait concept is similar to the inching concept, but is made much more capable by the maneuverability of the wheel-on-limb ATHLETE mobility system. With inching, each expansion and contraction of the suspension system carries the rover center of gravity

(CG) forward. In the SGait implementation, however, the kinematic capability of each limb allows the wheels to be repositioned with minimal effect on the CG position, which further reduces slipping in soft terrain. In addition, SGait can conform to a variety of terrain types, making the algorithm effective over a wider range of surface conditions.

This work was done by Julie A. Townsend, Curtis L. Collins, and Jeffrey J. Biesiadecki of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-47887.

Automated Generation of Adaptive Filter Using a Genetic Algorithm and Cyclic Rule Reduction

NASA's Jet Propulsion Laboratory, Pasadena, California

Modern datasets consisting of retrievals from space-based missions have target results, but often are accompanied by hundreds or thousands of other retrieved parameters or facts regarding a particular retrieval (e.g., pressure, temperature, spectral intensities). Many of the retrieval attempts fail due to complex or contaminated soundings, wasting precious computational time. This algorithm generates a filter based on all available metadata regarding a run that predicts whether it will converge or not.

Modern missions will generate so much data that only 6% of the record is

planned on being processed by the existing slow, CPU-intensive retrieval algorithm. This algorithm generates a filter that permits "sounding selection" to avoid attempted retrievals that would inevitably fail and thus waste CPU cycles.

Unlike linear regressions, Fischer analysis, or other standard machine learning techniques that examine the "bulk" of the data to create a "fit," this method utilizes a genetic algorithm that establishes upper and lower thresholds for each input feature. These thresholds are then optimized with a training dataset and reduced to the smallest

identical set of rules that generates the same filter output. This increases scientific interpretability later as to the mechanics of the filter's operation.

This work was done by Lukas Mandrake of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48254.

